REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-99-

0205

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
10 March 1999

3. REPORT TYPE AND DATES COVERED
1 March 97 to 1 March 1999

4. TITLE AND SUBTITLE
Process Design, Analysis and Simulation for Aluminum Extrusion Technology

5. FUNDING NUMBERS
F49620-97-1-0230

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR
801 North Randolph Street
Arlington, VA 22203-1977

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The aluminum extrusion process is briefly described and the role of process simulation discussed. Two systems for simulation based design (SBD) for three-dimensional aluminum extrusion process modeling are described. The first SBD system was developed using a LISP-based software framework. THe second SBD system for aluminum extrusion process modeling was developed usig Java and the Virtual Reality Modeling Language, and has a web browser-based user interface and is fully distributed. In both systems, geometric models and finite lement meshes are automatically constructed for profiles of varying shape. The finite element solution for a T-section extrudate is presented. Some of the remaining issues, which need to be resolved before the developed technologies can be applied to industrial applications are discussed.

19990903 008

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

DTIC QUALITY INSPECTED 4

Process Design, Analysis and Simulation for Aluminum Extrusion Technology: Process Modeling and Distributed Simulation-Based Design System Developments

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FINAL REPORT

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The aluminum extrusion process is briefly described and the role of process simulation discussed. We then describe two simulation-based design (SBD) systems for three-dimensional aluminum extrusion process modeling. The first SBD system was developed using a LISP-based software framework. The second SBD system for aluminum extrusion process modeling was developed using Java and the Virtual Reality Modeling Language, has a web browser-based user interface and is fully distributed. In both systems, geometric models and finite element meshes are automatically constructed for profiles of varying shape. The finite element solution for a T-section extrudate is presented. Some of the remaining issues which need to be resolved before the developed technologies can be applied to industrial applications are discussed.

Introduction

Extrusion is a process in which a material is forced through an orifice in the shape resembling the desired cross-section of the part. Aluminum extrusions are of interest because of the wide application of these structures in the aircraft industry. Aluminum is generally extruded under temperatures ranging from 450 C to 600 C using the direct (forward) extrusion process where a ram is used to force a billet of hot aluminum through a die to form an extrudate, which upon cooling, results in the final profile. Important considerations in the extrusion process are the shape, material properties and surface quality of the final part [1]. Unfortunately, these are difficult to determine a priori and, at present, the design of dies for the extrusion process is largely done by trial and error.

This report describes two Simulation-Based Design (SBD) systems for extrusion process modeling focusing on hot, direct extrusion through non-lubricated, flat-faced dies. Thermal coupling between the ram, container, die, billet, extrudate and environment are incorporated. The

billet and extrudate are modeled as a viscous fluid; the ram, container, and die as linear elastic solids.

Method

We developed two Simulation-Based Design (SBD) system frameworks during the course of this project. The knowledge-based engineering software Adaptive Modeling Language (AML) was used to develop the first extrusion SBD system [5]. Figure 1 shows the graphical user interface for this system. Shown on the left is a panel with options to create a system including an object model of the die, tooling, billet and extrudate, to modify this system, generate finite element meshes, solve extrusion problems numerically and visualize solution results. The system

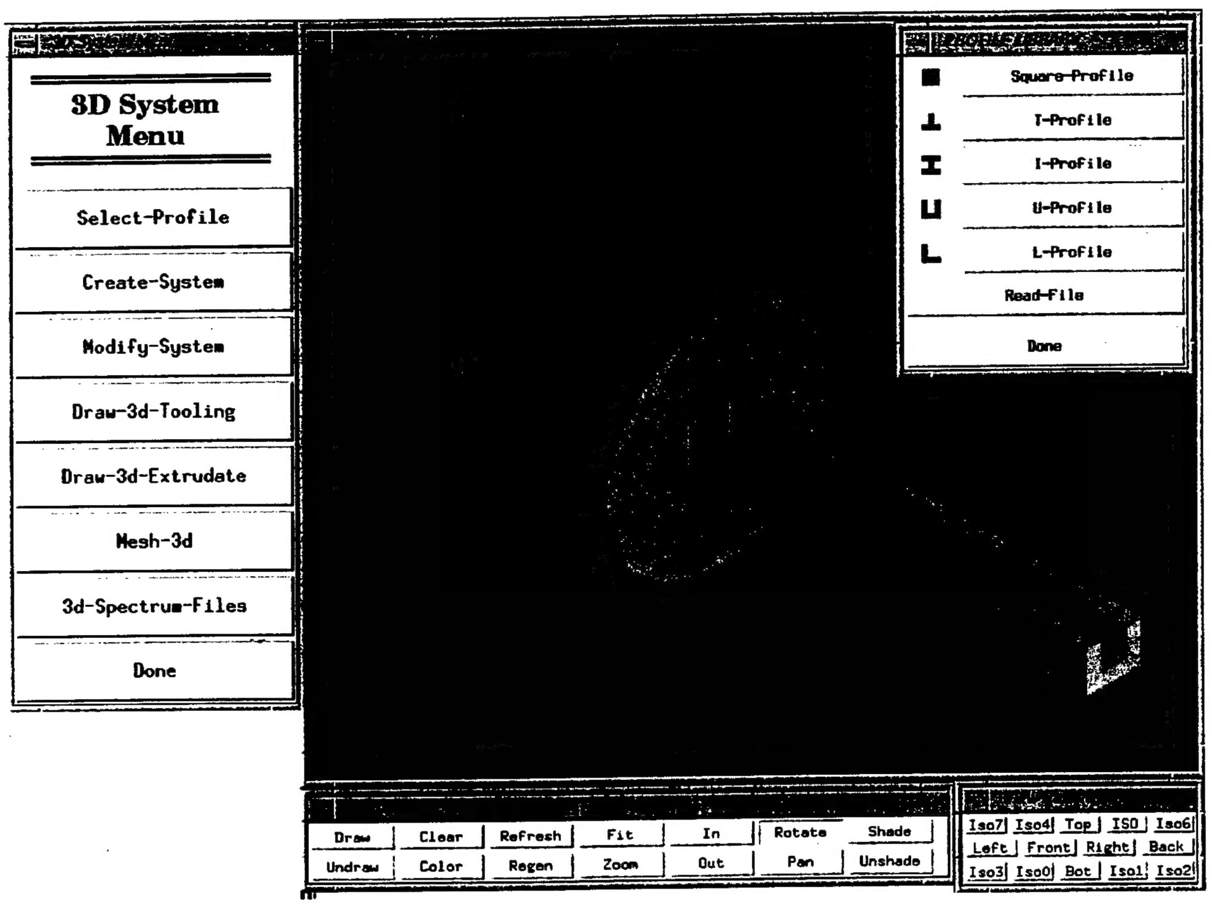
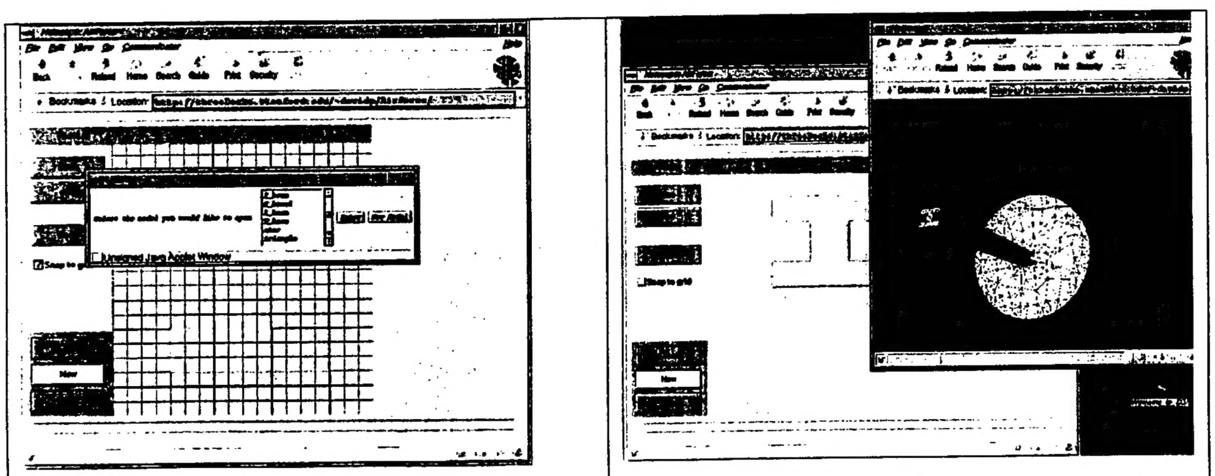


Figure 1. User interface for Simulation-Based Design system for extrusion simulations.

incorporates a profile library with standard cross-sectional shapes and the ability to define a user-desired profile. All of the models are parametrically defined. The geometric modeling kernel SHAPES was used for creating the solid models [4]. The finite element meshes for the solid and fluid regions were generated automatically using the SCOREC meshing tools [3]. Boundary

conditions were defined on the geometric model. The complete set of input files for the finite element solver, Spectrum, were generated automatically and, upon completion of the analysis, the Spectrum Visualizer was used to view the results [7].

The initial system, developed using the Adaptive Modeling Language (based on Common Lisp), required all of the software utilized to reside and run on the client computer, a Unix-based system. Because the computing power required to solve these problems would most likely not be affordable to an extrusion manufacturer, we developed a SBD system for extrusion process modeling employing a client-server paradigm. The World Wide Web (WWW), Virtual Reality Modeling Language (VRML) and the JAVA programming language were used to develop this system. Java binds easily to C/C++ code via the Java Native Interface (JNI), to enable distributed, cross-platform interaction between modules via the Remote Method Invocation (RMI) facility. Java enables the construction of graphical user interfaces, which may be configured as browser applets or standalone applications and which may execute locally or on a remote machine. Java's network compatibility can also facilitate integration of engineering databases used by extrusion manufacturers. We used the Java RMI and JNI to develop this distributed SBD system. In this system the user interface is the only application which runs on the client desktop computer and the geometric modeling, mesh generation and computational solution software resides and runs on different computers. The computation-intensive steps of geometric modeling, mesh generation, finite element modeling and visualization processing are performed on a single or multiple high-performance server at different locations. Figure 2 shows the user interface for this distributed SBD system for extrusion process modeling.



(a) (b)

Figure 2. User interface for Distributed SBD system running out of the Netscape browser showing (a) the 2-D sketchpad where a cross-section is drawn and (b) an I-beam cross-section shown in the background and the resulting surface of a finite element mesh of the billet and extrudate is shown in a VRML browser in the foreground.

The finite element method was used for the numerical simulations of the extrusion process. The aluminum was treated as a temperature-dependent Boussinesq viscous fluid using an arbitrary Lagrangian-Eulerian (ALE) framework [2]. The steel container and die were treated as temperature dependent hypoelastic solids. The input velocity and temperature of the aluminum are prescribed. The exterior of the extrudate was specified as a free surface exposed to ambient conditions, and convective thermal boundary conditions were specified on the exterior of the container and die.

A staggered solution method was employed with staggers for (1) the fluid and solid momentum equations, (b) thermal analysis and (c) the ALE mesh movement. A sparse direct solver with line search acceleration was used to solve the systems of equations. A time-stepping method with automatically adjusted time step sizes was employed to drive the solution to a steady state. This typically occurred within 100 time steps.

Results

The SBD system for both 2-D and 3-D analyses was completed. The results for the 2-D problems were described in detail in the prior progress report. Figure 3 displays finite element meshes for the tooling (container and die) and the billet and extrudate for a T-section model. Nodal and element boundary conditions and interface conditions are extracted by relating geometric surfaces to the generated mesh. Figure 4 displays finite element meshes for the billet and extrudate for four different profiles.

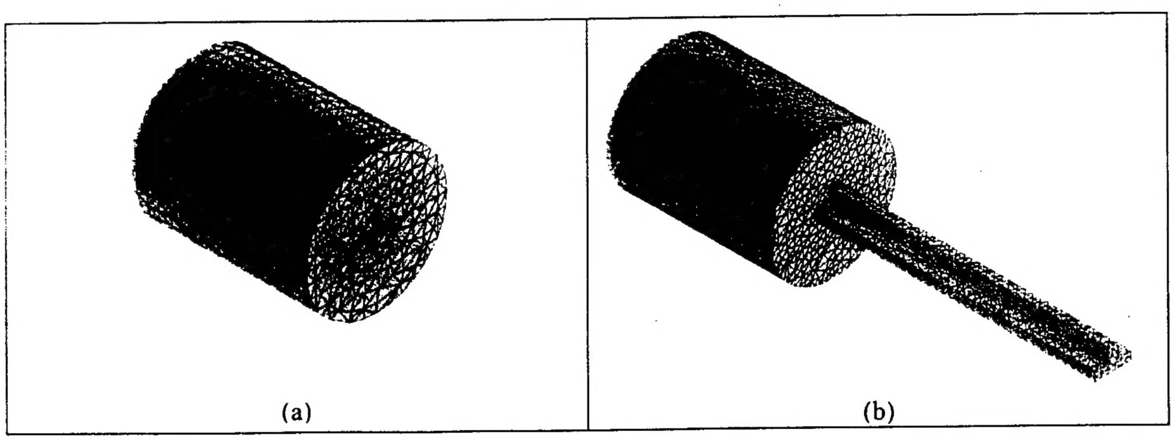


Figure 3. Finite element meshes for (a) tooling and (b) billet and extrudate for T-section model.

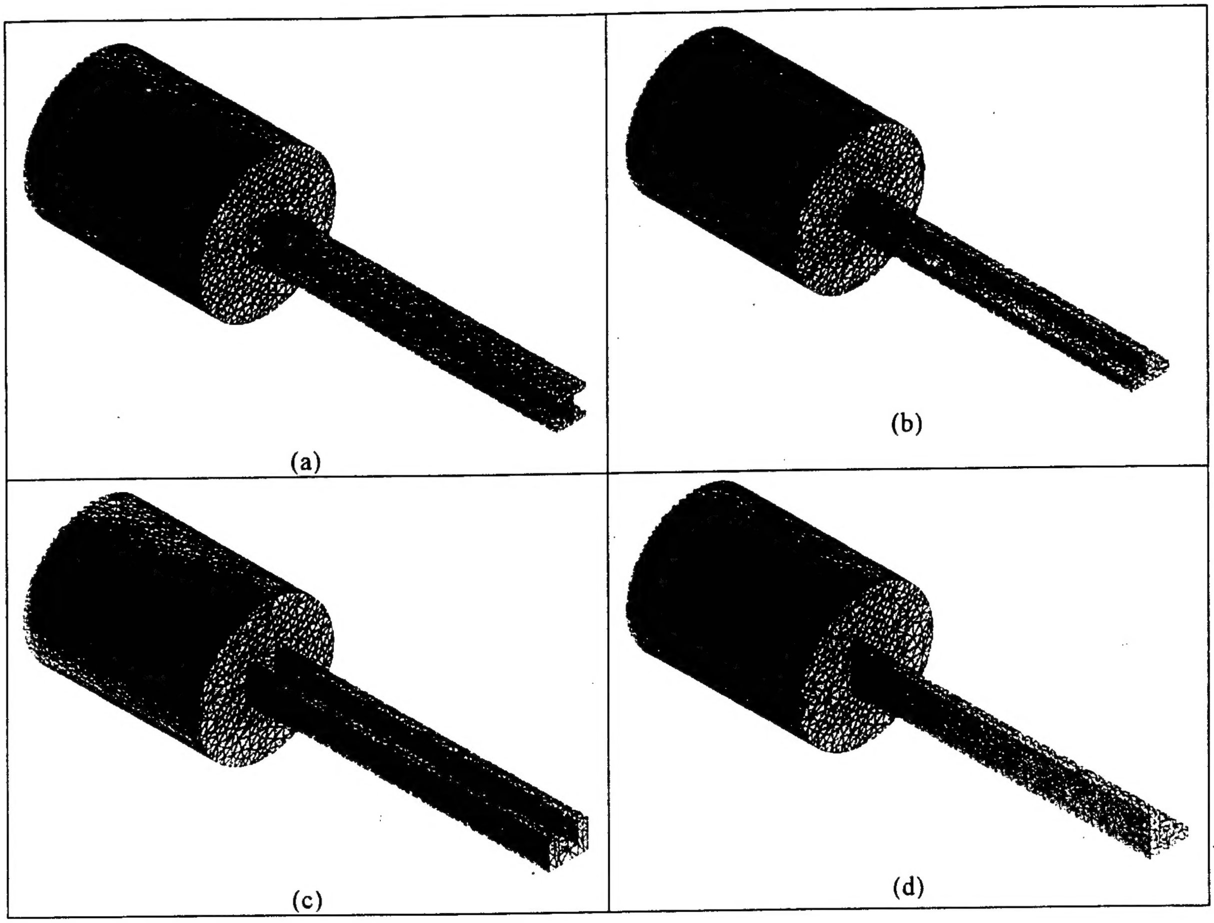


Figure 4. Geometric models for billet and extrudate of (a) I-section (b) T-section, (c) U-section, (d) L-section.

A three-dimensional computation of the extrusion of a T-section was performed. The discretization is still too coarse for the results to be useful to manufacturers but these computations are useful for the examination of material parameters, boundary conditions, and

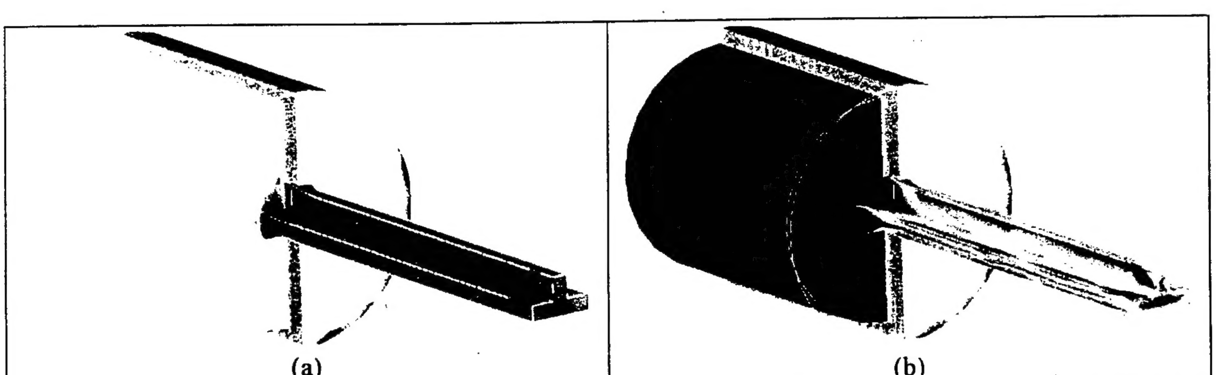


Figure 5. Results of extrusion simulation for T-section depicting (a) pressure distribution and (b) temperature distribution in extrudate.

solution methodology. The pressure distribution in the billet and extrudate are shown in figure 5a. Note the swelling of the extrudate in the neighborhood of the die. Figure 5b shows the temperature distribution in the billet and extrudate. The convective cooling of the extrudate is noted. Further examination of the thermal boundary conditions does appear to be warranted.

Conclusions

The finite element solution of three-dimensional extrusion problems is extremely challenging due to the combination of fluid, solid, and thermal effects. Significant progress has been made in the development of a Simulation-Based Design System for aluminum extrusion process modeling. We developed a Distributed SBD System whereby the models are constructed using a Java-based interface on a client and the modeling and computations are performed on a single or multiple high-performance servers. All of the model construction steps have been automated. Models have been constructed and analyses performed for square sections, I-sections, T-sections and U-sections.

In conclusion, the numerical solution of challenging industrial-caliber extrusion problems is on the horizon. Distributed SBD systems and new equation solving methods, implemented on high performance computers, will increase the accessibility of the simulation technology as well as ensuring the relevance of the computations performed.

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